(54) Title: METHOD AND APPARATUS FOR TRACKING A MOVING OBJECT

(57) Abstract: A method of tracking an object moving relative to a scene includes generating a background image from a plurality of images of the scene, dividing each image into a plurality of background image elements, determining a value of a characteristic of each said background image element for each image to obtain a set of values, and determining from the set of values a background value for each of the background image elements, then acquiring a pair of comparison images, dividing each comparison image into a plurality of comparison image elements and determining a comparison value of said characteristic for each of said comparison image elements, comparing each said comparison value with said background value of said corresponding background image element to thereby determine whether or not each said comparison image element is sufficiently similar to the corresponding background image element, and determining from which comparison image elements are not sufficiently similar to the corresponding background image element which comparison image elements relate to objects and determining a spatial characteristic of each said object, wherein objects in said pair of comparison images are matched by comparing spatial characteristics of objects of a following image of said pair of comparison images with spatial characteristics of objects of a preceding image of said pair of comparison images to match objects in the following image to objects in the preceding image. Each matched object is treated as a moving object to thereby track the movement of each said moving object relative to said scene.

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METHOD AND APPARATUS FOR TRACKING A MOVING OBJECT

Field of the Invention

5   The present invention relates to a method and apparatus for tracking a moving object.

Background of the Invention

10   There is an extensive literature concerned with the analysis of changing images and with the characterization of motion within images. Much of this work is based on the concept of optical flow. This allows the continuity equation of fluid dynamics to be applied

15   directly to image processing problems. Thus much of the extensive corpus of knowledge dealing with the manipulation of the partial differential equations used in fluid dynamics can be brought to bear on image processing problems.

20

          This approach has some serious shortcomings. The underlying assumptions that the domain of investigation, in this case the image intensity function, is everywhere continuous and differentiable is rarely true in practice.

25   The image intensity function is usually a function on a discrete domain of subscript values not on a continuum and rapid changes in intensity called "edges" are common in most images of interest. Such rapid changes in intensity preclude the use of Taylor's theorem in establishing the

30   underlying equations of the optical flow method. The practical consequence of this is that optical flow methods have not proven to be particularly successful in the processing of images. This is hardly surprising when one considers that the very features that facilitate the

35   alignment of images at an intuitive level, that is, sharp edges, have been sacrificed at the outset.

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Another approach is to divide the image domain into zones and detect the presence or absence of intensity differences within each zone. This method is limited by the coarseness of this subdivision, which decreases the spatial resolution, and by its inability to independently track two different objects when they pass one another.

Further, changes in pixel intensity can also be brought about by causes other than objects moving in the scene. In particular changes in scene illumination will cause significant changes in image pixel intensity. These intensity changes are then passed to downstream algorithms and give rise to spurious "moving objects" or false alarms. To some extent brightness compensating cameras ameliorate the problem but they cannot compensate for brightness changes that vary across the image.

Summary of the Invention

The invention provides a method of tracking an object moving relative to a scene, the method including:

(a)   generating a background image by acquiring a plurality of images of the scene, dividing each image into a plurality of background image elements, determining a value of a characteristic of each said background image element for each image to obtain a set of values, and determining from said set of values a background value for each of said background image elements;

(b)   comparing a pair of comparison images with said background image by:

(i)   acquiring a pair of comparison images, dividing each said comparison image into a plurality of comparison image elements corresponding to respective ones of the background image elements, and determining a comparison value of said characteristic for each of said comparison image elements;

(ii)   comparing each said comparison value

with said background value of said corresponding background
image element to determine whether said comparison value is
sufficiently similar to said background value to thereby
determine whether or not each said comparison image element
5 is sufficiently similar to the corresponding background
image element; and

(iii)   determining from which comparison image
elements are not sufficiently similar to the corresponding
background image element which comparison image elements
10 relate to potential objects and determining a spatial
characteristic of each said potential object;

(c)   matching potential objects in said pair of
comparison images by comparing spatial characteristics of
potential objects of a following image of said pair of
15 comparison images with spatial characteristics of potential
objects of a preceding image of said pair of comparison
images to match potential objects in the following image to
potential objects in the preceding image; and

(d)   treating each matched potential object as a
20 moving object to thereby track the movement of each said
moving object relative to said scene.

The invention also provides a method of reducing
the effect of variations in intensity of illumination of a
25 scene, the method including:

converting intensity values of image elements of
images acquired of said scene to a logarithmic scale of
intensity to thereby form a log-intensity image; and

filtering said log-intensity image with a high-
30 pass spatial filter in order to create an output image of
said scene which is independent of the illumination of the
scene.

The invention also provides a method of tracking
35 an object added to or removed from a scene, the method
including:

(a)   generating a series of background images of the

scene by acquiring for each background image a plurality of
images of said scene, dividing each said image into a
plurality of background image elements, determining a value
of a characteristic of each background image element for
5   each image to obtain a set of values and determining from
said set of values a background value for each of said
background image elements;

(i)   comparing each new background value
with an old background value of a corresponding background
10 image element of an old background image which precedes
said new background image by a number of background images
to determine whether said new value is sufficiently similar
to said old value to thereby determine whether or not each
new image element is sufficiently similar to the
15 corresponding old image element;

(ii)   determining from which new image
elements are not sufficiently similar to the corresponding
old image element which new image elements relate to
potential objects and determining a spatial characteristic
20 of each said potential object;

(b)   matching potential objects in consecutive
background images by comparing spatial characteristics of
potential objects of a following background image of said
consecutive images with spatial characteristics of
25 potential objects of a preceding background image of said
consecutive background images to match potential objects in
the following image to potential objects in the preceding
image; and

(c)   treating each matched potential object as an
30 object added to or removed from the scene.

The invention also provides apparatus for
tracking an object moving relative to a scene, the
apparatus including:
35 (a)   image acquisition means;

(b)   background image generation means for generating
a background image from a plurality of images of the scene

acquired by said image acquisition means, said background
image generation means dividing each image into a plurality
of background image elements, determining a value of a
characteristic of each said background image element for
5   each image to obtain a set of values, and determining from
said set of values a background value for each of said
background image elements;

(c)   image comparison means for comparing a pair of
comparison images with said background image by:

10   (i)   dividing each image of a pair of
comparison images acquired by said image acquisition means
into a plurality of comparison image elements corresponding
to respective ones of the background image elements, and
determining a comparison value of said characteristic for
15   each of said comparison image elements;

(ii)   comparing each said comparison value
with said background value of said corresponding background
image element to determine whether said comparison value is
sufficiently similar to said background value to thereby
20   determine whether or not each said comparison image element
is sufficiently similar to the corresponding background
image element; and

(iii)   determining from which comparison image
elements are not sufficiently similar to the corresponding
25   background image element which comparison image elements
relate to potential objects and determining a spatial
characteristic of each said potential object;

(d)   object matching means for matching potential
objects in said pair of comparison images by comparing
30   spatial characteristics of potential objects of a following
image of said pair of comparison images with spatial
characteristics of potential objects of a preceding image
of said pair of comparison images to match potential
objects in the following image to potential objects in the
35   preceding image; and

(e)   object tracking means which treats each matched
potential object as a moving object to thereby track the

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movement of each said moving object relative to said scene.

The invention also provides apparatus for
reducing the effect of variations in intensity of
5   illumination of a scene, the apparatus including:
    logarithmic conversion means for converting
intensity values of image elements of images acquired of
said scene to a logarithmic scale of intensity to thereby
form a log-intensity image; and
10   a high-pass spatial filter for filtering said
log-intensity image in order to create an output image of
said scene which is independent of the illumination of the
scene.

15   The invention also provides apparatus for
tracking an object added to or removed from a scene, the
apparatus including:
    (a)   image acquisition means;
    (b)   background image generation means for generating
20 a series of background images of the scene, said background
image generation means generating each background image
from a plurality of images of said scene acquired by said
image comparison means, said background image generation
means dividing each said image into a plurality of
25 background image elements, determining a value of a
characteristic of each background image element for each
image to obtain a set of values and determining from said
set of values a background value for each of said
background image elements;
30   (i)   background comparison means for
comparing each new background value with an old background
value of a corresponding background image element of an old
background image which precedes said new background image
by a number of background images to determine whether said
35 new value is sufficiently similar to said old value to
thereby determine whether or not each new image element is
sufficiently similar to the corresponding old image

element;

(ii)   determining from which new image elements are not sufficiently similar to the corresponding old image element which new image elements relate to

5   potential objects and determining a spatial characteristic of each said potential object;

(c)   object matching means for matching potential objects in consecutive background images by comparing spatial characteristics of potential objects of a following

10 background image of said consecutive images with spatial characteristics of potential objects of a preceding background image of said consecutive background images to match potential objects in the following image to potential objects in the preceding image; and

15 (d)   object tracking means which treats each matched potential object as an object added to or removed from the scene.

Brief Description of the Drawings

20

In order that the present invention may be understood, examples of an embodiment of two aspects of the invention will be described with reference to the accompanying drawings. In the drawings:

25   Figure 1 shows a background image of a street scene;

Figure 2 shows a new image which contains a human figure;

Figure 3 shows the Boolean pixel array that is

30 formed when the new image is tested against the range images;

Figure 4 shows a Boolean tile array formed from the Boolean pixel array;

Figure 5 shows a smoothed Boolean tile array

35 formed by smoothing the Boolean tile array;

Figure 6 shows an image of a scene in overcast conditions;

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Figure 7 shows an image of same scene in sunlit conditions and with a person in the foreground;

Figure 8 shows an image which is obtained when the image of figure 6 is converted using a logarithmic
5   intensity scale;

Figure 9 shows an image obtained when the image of figure 7 is similarly converted;

Figure 10 shows an image obtained when the image of figure 8 is convoluted with a high-pass integrating
10   filter; and

Figure 11 shows an image obtained when the image of Figure 9 is similarly treated.

Description of the Preferred Embodiments
15

The preferred embodiment of the first aspect of the present invention is particularly suited to cases where the moving objects account for only a small proportion of the intensity variance of the image. The process operates
20   upon a regularly timed sequence of images of one or more objects moving against a static background. The image data generated by an image acquisition means in the form of a camera or video recorder passed by means of a video capture card and its associated software to a computer programmed
25   to carry out the object tracking method. Software to carry out the method can be generated by any skilled programmer and therefore description of suitable software is not included herein.

30   Where the objects being tracked are humans, 5 to 6 frames per second is sufficient to enable an object to be tracked. The frame rate can be varied in accordance with the anticipated maximum velocity of the objects being tracked.
35

A background image such as that shown in Figure 1 is prepared by a background generation means from a

sequence of background images of the scene. Each background image is divided into a plurality of background image elements. The background image elements are chosen to be each pixel of the image but could be a group of pixels. A

5 background value of a characteristic of the background image is determined for each pixel. In the preferred embodiment, the characteristic of the background image is chosen to be the intensity of the image. Thus there is a time series of intensity values for each pixel. Each value

10 in the time series corresponds to one image in the sequence. This time series is binned to form a sample distribution of intensities for the given pixel and the mode or most common value of intensity is found for each pixel. This value is assigned to the corresponding pixel in

15 the background image which thus constitutes background data against which other images can be compared. The mean or median can be used but are not as efficient. Objects that are moving in the scene will affect the values in the outlying bins of the sample distribution of intensities as

20 they pass by the pixel but they will not, in general, affect the mode. Hence most moving objects will be invisible and only fixed and slowly moving objects will affect the background data represented by the background image. That is, the background image is effectively an

25 array of background values which can be used as a basis of comparison.

    Two "confidence limit images" or "range images" are derived by the background image generation means from

30 the background image, a "high range image" and a "low range image". For each pixel in the background image, an intensity value is added to form the high range image and an intensity value is subtracted to form the low range image. The value to be added and subtracted may be a

35 constant derived from a prior knowledge of the camera noise statistics or it may be estimated for each pixel from the sample distribution of intensity values for that pixel by

the usual methods of estimating confidence limits.

More specifically, the modal and upper and lower
confidence limit images are calculated as follows. A modal
5   image is constructed from a sequence of (say) 50 images as
follows - For each pixel, an array of (say) 64 "bins" is
set up and the bins are assigned zero value. The intensity
value (which must lie between 0 and 255) for that pixel for
each image is used to calculate a bin number, j, by
10   dividing the intensity, I, by 4 and bin(j) is incremented
by one. After 50 images have been processed in this way
there is a numerical distribution of intensity for each
pixel. The mode (most common value) of intensity for each
pixel is found to form a background or "modal" image. The
15   mode is chosen rather than the mean because outliers caused
by objects moving past the pixel corrupt the mean. This
gives rise to a "double exposure" effect in the background
image. On the other hand outliers do not affect the mode
providing there are not too many of them and passing
20   objects are rendered invisible. The median would probably
do just as well but the mode is easier to calculate.

When the mode is being computed the upper and
lower confidence limits for each pixel are calculated at
25   the same time from the same numerical distribution of
intensity values by finding the root mean square of the
difference between the binned intensities and the mode.
This root mean square value is very close to but not quite
the same thing as the standard deviation, the latter being
30   the root mean square difference from the mean. Adding and
subtracting twice the root mean square to the mode give the
upper and lower confidence limits respectively. These
values will be similar to the 95% confidence limits found
by assuming a Gaussian distribution and using twice the
35   sample standard deviation or those found using Student's t-
test. Because of the presence of outliers, which equate to
objects which the technique of the present invention

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detects, a Gaussian assumption is not justified.

Once the two background range images have been
formed each new comparison image acquired by the image
5   acquisition means, such as that shown in Figure 2, is
compared by an image comparison means with the background
image to find potential new or moving objects in the scene.
This is done pixel by a pixel - i.e. each pixel in the
comparison image has its intensity determined by the image
10 comparison means and compared with the intensity of the
corresponding pixel in the background image to determine
whether the comparison value of intensity is sufficiently
similar to the background value of intensity. If the
intensity of a pixel in the incoming frame lies between the
15 intensities of the same pixel in the low range and high
range images then the pixel is designated as a "False"
pixel. If it lies outside the range then the pixel is
designated as a "True" pixel, that is, one which is
significantly different from the background image. This
20 process generates a two-dimensional Boolean pixel array of
"True" and "False" pixels. The Boolean pixel array
generated by the image in Figure 2 is shown in Figure 3.
The Boolean pixel array contains a large area of True cells
1 which are caused by the presence of the human figure in
25 Figure 2 - i.e. by the presence of a moving object. It also
contains true cells 2 which are due to noise in the new
image. Initially each pixel that falls outside the range is
presumed to relate to an object. Further processing of the
pixels by a noise reduction means and the object matching
30 means progressively eliminates pixels falling outside the
range that do not relate to objects.

The image plane is then uniformly subdivided by
noise reduction means into groups of pixels called tiles,
35 where each tile contains an array of adjacent pixels. The
Boolean pixel array is then used to generate a Boolean tile
array by designating those tiles with more than, say, one

half of their pixels true as "True" tiles and the rest as "False". This tiling process is not essential but it greatly increases the speed of the ensuing steps and also reduces noise by reducing the number of image elements

5   which are presumed to relate to objects and hence reducing the number of image elements treated as objects. The Boolean tile array derived from the Boolean pixel array of Figure 3 is shown in Figure 4.

10   The Boolean tile array may be smoothed by the noise reduction means to form a smoothed Boolean tile array. A new tile array is prepared which has the same dimensions as the Boolean tile array. Each cell in the Boolean tile array is tested to see how many of the

15   surrounding tiles are true. If the number exceeds a preset threshold the corresponding cell in the smoothed Boolean tile array is set to True and to False otherwise. This is similar to passing a 2 dimensional moving average filter over numerical data. It is not essential but helps to

20   eliminate protrusions such as shadows. The smoothed Boolean tile array derived from Figure 4 is shown in Figure 5.

          The tiles in the smoothed Boolean tile array are then formed into groups of proximate tiles by the noise

25   reduction means. A true tile that lies within a predefined distance of a given true tile is allocated to the same "space group". Each space group is treated as an object by an object matching means. True tiles do not necessarily have to touch to belong to the same group (hence they are

30   "proximate" rather than "contiguous"). The proximity thresholds, the predefined distances in the x and y directions, which define proximity, may be functions of position in the image and of the scene geometry. They may be made larger near the bottom of the image where objects

35   in the scene are closer to the camera. The proximity thresholds may also be varied according to the type of object being viewed and may be set differently if vehicles

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are being viewed rather than people.

Once the space groups have been formed their
statistical properties are computed by the object matching
5   means in order to obtain a spatial characteristic for each
object. These properties include the centroid of the group
and its spatial standard deviations in the x and y
directions in units of inter-pixel distance.

10   Tens of thousands of pixel values in the incoming
frame are reduced by 3 or 4 orders of magnitude to a much
smaller number of space group statistics; bitmap data has
been converted to vector data.

15   Each space group is assumed to correspond to one
or more real objects moving in the scene. Since solid
objects are constrained by the laws of physics to move
smoothly from frame to frame, proximity in time is as
important as proximity in space when tracking real objects.
20   For this reason space groups which are by their nature
associated only with a single frame are incorporated into
"time groups" which persist over many frames. The space
groups of each new frame are compared with time groups
derived from preceding frames to see if any matches can be
25   found. A time group may consist simply of a single space
group from a single frame or it may persist for many
consecutive frames. Time groups which do not persist for a
number of frames are discarded and not treated as objects.
In the preferred embodiment time groups are discarded if
30   they don't persist for more than three frames.

A space group is allocated to a time group if the
centroid of the space group is sufficiently close to the
centroid of the time group and if the spatial standard
35   deviations of the space group are sufficiently close to the
spatial standard deviations of the time group. Space groups
which are matched to time groups are used by the object

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tracking means to track moving objects.

If a single match is found by the object matching
means the space group is added to that time group. If more
5   than one space group matches a time group the one with the
best match is chosen. If no space groups match an existing
time group, the time group is killed off. If no time groups
match a space group a new time group is started. When a
space group is added to a time group the statistics of the
10   space group are used to update the statistics of the time
group. The centroid of the space group is added to a list
of coordinate pairs associated with the time group and its
spatial variance data are incorporated into the spatial
variance data of the time group. The distance matching
15   thresholds are not absolute but are based on the spatial
size of the groups as summarized by their spatial standard
deviations. The size matching criterion is based on a
"matching factor" which is a function of the ratio of the
spatial standard deviations of the space group to those of
20   the candidate time group. More specifically, the centroid
and spatial standard deviation of each space group is
calculated first. The centroid and spatial standard
deviations of each time group are calculated from the sums
and sums of squares of its member space groups.
25

The spatial standard deviations are the square
roots of the spatial variances in the x and y directions.

When a candidate space group is tested for a
30   match with a given time group it has to pass all four of
the following tests before it is considered as a possible
match -

1.   Is the x-coordinate of the centroid of the
35   space group (i.e. the mean x-value of the
group) closer than the x-distance-tolerance
to the x-coordinate of the centroid of the

time group?

2.   Is the y-coordinate of the centroid of the
      space group closer than the y-distance-
      tolerance to the y-coordinate of the
      centroid of the time group?

3.   Is the x-size-factor less than the size
      factor threshold?

4.   Is the y-size-factor less than the size
      factor threshold?

These tests can be expressed as follows:

$$(x_s - x_t)^2 \quad < \quad G \ \max(s_x, t_x) \tag{1}$$

$$(y_s - y_t)^2 \quad < \quad G \ \max(s_y, t_y) \tag{2}$$

$$| t_x - s_x | \ / \ (t_x + s_x) < \quad F \tag{3}$$

$$| t_y - s_y | \ / \ (t_y + s_y) < \quad F \tag{4}$$

where x_s is the x-coordinate of the centroid of
the space group, x_t is the x-coordinate of the centroid of
the time group, s_x is the x-variance of the space group, t_x
is the x-variance of the time group, G is a constant
between 2 and 10 and F is a constant between .5 and 1.5.
The y-direction quantities are similarly defined.

Optimum values of G and F have been found by the
inventors to be 6.0 and 1.0 respectively.

Time groups can be visualized as groups of true
tiles in a 3 dimensional space in which the dimensions are
the pixel coordinates and the frame number. When a time
group is terminated, that is when no space group can be

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found which matches it or when it has persisted for a
preset number of frames (usually ten frames), the time
group is converted to a line segment. This involves the
object tracking means fitting a straight line to the list
5   of space group centroid coordinates associated with the
time group.

Each line segment is a straight line in (x, y, t)
space. The slope of this line provides an estimate of the
10 velocity of an object moving in the scene to which the line
segment is assumed to correspond.

Just as space groups were built up into time
groups, line segments are built up into lines or
15 "trajectories" by the object tracking means. When a line
segment is formed it is projected backwards in time to see
if it lies close to the most recent segment of an existing
trajectory. If more than one trajectory is found the
closest is chosen. If no suitable trajectories are found
20 then the line segment is made the first side of a new
trajectory. When a new line segment is projected backward
it is also checked to see if it intersects the boundaries
of the scene. If so an "entrance" has occurred and a new
trajectory is started. Likewise the most recent side of
25 each existing trajectory is projected forward in time to se
if it intersects a boundary. If it does an "exit" has
occurred and the trajectory is terminated and excluded from
further consideration. When matching a line segment to a
trajectory, a test is also carried out to see if the
30 concatenation involves an unrealistically high
acceleration. If so the concatenation is abandoned.

It will thus be understood that a trajectory
represents the movement of an object and also consists of a
35 series of line segments. Each line segment corresponds to
a time group. The length of the time group will vary
depending on the number of frames for which the time group

persisted. In the preferred embodiment, time groups which
persist for three or less frames are discarded on the
assumption that if they do not persist for a sufficient
time they cannot relate to a moving object. The length of
5   each time group is capped at ten frames. The number of
frames chosen as the maximum length for each time group is
chosen in dependence of two factors:

     (1)   the number of centroids which are used to
          produce a line segment and hence the extent
10   to which the line segment correctly
          approximates the position of the centroids;
          and

     (2)   the smoothness of the resulting trajectory.

15   It has been found that ten frames provides a good
balance between these factors. However, the choice of
frames will be dependent on the application. For example,
if many images are taken of slowly moving objects, the
length of the resulting line segments would have less
20   effect on the curve of the trajectory and hence more frames
could be used to make up each time group.

       A trajectory tracks the motion of an individual
object in the scene. At any given time, t, the
25   spatial coordinates, (x, y), of the centroid of the object
can be calculated or predicted by extrapolating the
preceding line segment. This position information can be
used to mark the object being tracked for display purposes
or to keep a record of the movement of a particular object
30   in the scene. It can also be transmitted from the computer
in order to control another device such as an automatic
pan-tilt head fitted with a second, high-resolution camera.

       When objects pass one another so that their space
35   groups temporarily coalesce then separate again, the
extrapolation of line segments allows both the objects to
be tracked and their separate identities maintained.

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Each trajectory summarises the size, shape and
kinetic behavior of a single object in the scene. The
characteristics of a trajectory and/or its component line
segments allow objects and behaviors to be distinguished
5   and selectively reported. Thus trajectories with line
segments having velocities above a preset threshold may
indicate the presence of persons running, fighting or
skateboarding. A trajectory enduring for a longer than a
preset threshold time would indicate a person loitering in
10 the scene. The size of the line segments as recorded in
their spatial standard deviations is also a distinguishing
characteristic and allows adults to be distinguished from
children and animals, vehicles to be distinguished from
people and vehicle types to be distinguished from one
15 another.

It should be understood that the present ·
invention is not confined to the above-described
embodiment.

20   The term "intensity" which is used in the above
description may be generalised to include any other
quantifiable characteristic of an image pixel such as hue
or saturation.

25   In a real environment the background image needs
to be continually refreshed to allow for slow changes in
the scene. A new background image is created every 100
frames or so, from which moving objects have been largely
removed. This provides an opportunity to detect static
30 objects that have recently appeared in the scene or
disappeared from the scene. Each new background image
(rather than each new comparison image) is compared by a
background image comparison means with a pair of range
images that have been saved some time previously. Typically
35 the third last background image is used. In this case the
process need only be taken as far as computing the line
segments. That is, each background image is compared first

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with a background image which precedes it in time by three
background images to determine changes in the scene in the
intervening period. That is, the mode of each new
background image is compared with the confidence limits of
5   the old background image to determine whether there have
been any changes. Each change is treated as a slow moving
object. The potential slow moving objects are then matched
with potential slow moving objects of preceding background
images to determine whether a change has persisted over
10   consecutive frames. Any object which persists sufficiently
long enough (typically for three background images) is
recognised as being a change to the scene. A changed static
object in the scene will give rise a new line segment that
persists in consecutive background images. The size of the
15   static object to which it corresponds may be estimated as
before, allowing parcels to be distinguished from vehicles
etc.

Another problem that besets this method of image
20   comparison is the occurrence of pixels that are noisy due
to environmental reasons. For example shiny objects
reflecting moving clouds, wind blown vegetation, the
shadows of wind blown vegetation and the shadows of tall
buildings moving with the sun's motion in the sky. The
25   algorithms described above for constructing space groups
and time groups are sufficiently robust to allow pixels to
be masked with little deterioration in performance. Pixels
from problem areas can be made self-masking by computing
the proportion of time for which each pixel is True. On a
30   sufficiently long time scale any given pixel should only be
true for a small proportion of the time. Any that are not
can be designated as "noisy" pixels and excluded from
consideration when the Boolean pixel array is formed by a
masking means.
35

The second aspect of the invention relates to a
high-pass spatial filtering process suitable for use in

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combination with the object tracking method of the first
aspect of the invention. In the embodiment of the second
aspect of the invention a background image shown in Figure
6 and a current image shown in Figure 7 were firstly

5   converted to a new scale to give the images shown in
Figures 8 and 9 respectives. Each image is composed of a
plurality of pixels and the shading of the pixels
represents their intensity value. The function used to
convert the intensity value of each pixel, I, in each image

10   to log-intensity, L, was defined as:

$$L \quad = \quad m \log(\ I\ ) + c \qquad \text{for} \quad 4 \leq I < 256$$

$$\text{and} \qquad L \quad = \quad I \qquad \qquad \text{for} \quad 0 \leq I < 4\ ,$$

15

where $m\ =\ 42\ /\ \log(\ 2\ )$ and $c = -80$.

The function was made linear for very small
intensity values to avoid the numerical complications of

20   large negative values of L as I approached zero. The
parameters m and c were chosen so that intensity values
between 4 and 255 mapped into the same range (4 to 255)
for computational convenience. The conversion is made
computationally efficient by computing 256 table entries

25   only once at the outset and then finding the appropriate
value of L for each pixel by table look-up.

Next the rescaled images shown in Figures 8 and 9
were filtered by convoluting them, firstly with filter

30   coefficients, a_i , in Table 1 in the horizontal direction,
and then with the filter coefficients, b_j , in Table 2 in
the vertical direction.

a_0	a_1	a_2	a_3	a_4	a_5	a_6	a_7	A_8
-1	-8	-12	8	26	8	-12	-8	-1

35   Table 1

b_0	b_1	b_2	b_3	b_4	b_5	b_6
1	6	15	20	15	6	1

Table 2

Finally the logarithmically scaled, filtered images were decimated by 2 both horizontally and vertically to give the images shown in Figures 10 and 11. Because the filtering process gave rise to negative values of intensity, the intensities were adjusted to lie between 0 and 255 for display purposes. In these figures the value zero is represented by middle grey, negative values are darker than this and positive values are lighter. Comparison of Figures 10 and 11 shows that only real differences in the scene - i.e. due to the figure in the foreground, are apparent and that the effects of the different illumination conditions have been removed.

It should be evident from the above that this aspect of the invention stems from the realization that changing the illumination of a scene changes the intensities of differently coloured objects in the image in a constant ratio. On the other hand most image processing operations are additive and subtractive rather than multiplicative. By converting intensity, I, to the scaled logarithm of intensity, L, this difficulty is overcome. If the scene illumination increases, the values of I for each pixel should all increase by a constant ratio and it follows that the values L for each pixel should all increase by a constant increment.

In practice the illumination of different parts of a scene may not change by the same amount over the entire scene. Nevertheless objects that are close together in the scene will, in general, experience similar

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illumination changes. It follows that pixels that are close together in the image should take values of L that vary by the same absolute amount and that in general the differences in L between neighbouring pixels will be
5   constant and independent of the illumination of the scene.

It follows that the logarithmic rescaling of an image as described above followed by convolution with any differencing filter will give rise to a new image which is
10 independent of the illumination of the scene. Unfortunately the simple differencing of neighbouring pixels will greatly decrease the signal to noise ratio of the image. L is always positive so that the difference, ΔL, is usually much less than L itself. On the other hand the variance of the
15 camera noise is the sum of the variances of each individual pixel. In general this relative increase in noise will be intolerable.

This problem can be overcome by combining the
20 differencing operation with an integrating operation whereby the L values of a number of neighbouring pixels are added together in order to increase the signal to noise ratio of the resulting sum. This is the major function of the convoluting filters whose coefficients are listed in
25 Tables 1 and 2. The filter of Table 2 is purely an integrating filter. The filter of Table 1 is similar but the coefficients add to zero. Thus the z-transform has a zero at $1 + 0i$ and the Fourier transform is zero at zero frequency. This means that the filter is a broadband, high-
30 pass filter that detects broad edges in the horizontal direction. Experiments showed that there was no need for high pass filtering in the vertical direction as well as in the horizontal direction. Such additional filters tended to exaggerate the presence of rooftops and fence lines in an
35 undesirable way.

The use of the filters had the effect of blurring

the image. This blurring allows the image to be decimated without this leading to the aliasing effects that would occur in the absence of filtering. The effects of camera vibration are also greatly reduced. Decimation in this way

5   leads to improvements in the speed of downstream processing algorithms since there are fewer pixels to be processed in each frame.

It should be appreciated that this aspect of the

10 invention is not limited to the above-described embodiment. In particular the filter coefficients were chosen specifically for distinguishing human scale objects positioned metres or a few tens of metres from the camera. Many other high-pass integrating filters are possible and

15 may work better in different applications. Integration and decimation may not be desirable where high resolution is required. In well-lit environments in which intensity changes are uniform across the scene, the average log-intensity of the whole image can be subtracted from the

20 log-intensity for each pixel and any other high-pass filtering can be dispensed with.

The filter desirably meets the following conditions:

25

1.   Its transfer function should be zero at zero frequency i.e. at $z = 1 + 0i$ in the z-plane,

2.   It should minimize the variance of intensity

30   over the time coordinate relative to the variance in intensity over the spatial coordinates in order to minimize the effect of camera noise relative to the "signal", and

35

3.   It should be well behaved and not give rise to aliasing and Gibbs effects.

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Condition 1 implies that the coefficients must add to zero. Condition 2 is best achieved by having a single negative coefficient with a large absolute value balancing the remaining coefficients which all take the
5   same small positive value. Condition 3 is best achieved by convoluting a one dimensional filter which satisfies the first two conditions with simple one dimensional Gaussian or Pascal's triangle coefficients. The convolution is carried out first in one direction and then in the other to
10   give a two dimensional spatial filter with the desired characteristics. The order of the convolutions in the x and y directions is irrelevant.

The first and second aspects of the invention may
15   be combined, by employing the high-pass spatial filter of the second aspect of the invention each time an image, whether that be a background image or a comparison image, is acquired. These images can thus be used as the basis of the comparison if the determination of which pixels are
20   true and false pixels and hence to determine true and false tiles and carry out the remaining steps of the first aspect of the invention.

Herein, the embodiments of aspects of the methods
25   of invention have been described as being carried out by a computer programmed with software written to carry out the various steps of the method. However, it will be understood that equivalent hardware could be employed to carry out the invention. Further, it will be understood
30   that steps such as determining a characteristic value for each image element may be performed by a separate means which embodies a sub-routine and this sub-routine may be shared by other means to carry out this part of the method.

35

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1.   A method of tracking an object moving relative to
a scene, the method including:

5   (a)   generating a background image by acquiring a
plurality of images of the scene, dividing each image into
a plurality of background image elements, determining a
value of a characteristic of each said background image
element for each image to obtain a set of values, and

10 determining from said set of values a background value for
each of said background image elements;

(b)   comparing a pair of comparison images with said
background image by:

(i)   acquiring a pair of comparison images,

15 dividing each said comparison image into a plurality of
comparison image elements corresponding to respective ones
of the background image elements, and determining a
comparison value of said characteristic for each of said
comparison image elements;

20   (ii)   comparing each said comparison value
with said background value of said corresponding background
image element to determine whether said comparison value is
sufficiently similar to said background value to thereby
determine whether or not each said comparison image element

25 is sufficiently similar to the corresponding background
image element; and

(iii)   determining from which comparison image
elements are not sufficiently similar to the corresponding
background image element which comparison image elements

30 relate to potential objects and determining a spatial
characteristic of each said potential object;

(c)   matching potential objects in said pair of
comparison images by comparing spatial characteristics of
potential objects of a following image of said pair of

35 comparison images with spatial characteristics of potential
objects of a preceding image of said pair of comparison
images to match potential objects in the following image to

potential objects in the preceding image; and

(d)   treating each matched potential object as a
moving object to thereby track the movement of each said
moving object relative to said scene.

2.   A method of tracking an object as claimed in
claim 1, wherein determining said background value involves
determining the mode of said set of values.

3.   A method of tracking an object as claimed in
claim 1 or claim 2, wherein determining said background
value of said characteristic involves determining a range
of background values, and said comparison value is
determined to be sufficiently similar to said background
value if said comparison value is within said range.

4.   A method of tracking an object as claimed in
claim 3, wherein said range of background values is
determined by calculating upper and lower confidence limits
about the mode of said set of values.

5.   A method of tracking an object as claimed in any
one of claims 1 to 4, wherein said pair of comparison
images are consecutive images in a series of comparison
images and each comparison image is compared with said
background image to determine which comparison image
elements relate to potential objects and wherein potential
objects in a following image are matched to potential
objects in a plurality of preceding images before being
treated as a moving object.

6.   A method of tracking an object as claimed in
claim 5, wherein the spatial characteristics of potential
objects of a plurality of preceding images are combined to
produce a combined spatial characteristic for each
potential object and the spatial characteristic of the
following object is compared to the combined spatial

characteristic.

7.   A method as claimed in any one of claims 1 to 6,
wherein determining which comparison image elements relate
5   to objects includes processing each comparison image
element which is not sufficiently similar to the
corresponding background image element to reduce the effect
that noise has on image elements being treated as objects.

10   8.   A method as claimed in claim 7, wherein said
image elements are pixels and said pixels are grouped into
tiles made up of an array of pixels so that said image is
divided into a plurality of tiles, and wherein said
processing involving determining whether or not the
15   majority of comparison image elements in said tile are
sufficiently similar and treating each tile which has a
majority of image elements which are not sufficiently
similar as an object.

20   9.   A method as claimed in claim 8, including
determining whether each said tile is sufficiently related
to others of said tiles to be an object, grouping said
sufficiently related tiles, and treating said sufficiently
related group of tiles as said object.
25
10.   A method as claimed in any one of claims 1 to 9,
wherein said spatial characteristic includes the centroid
of the object.

30   11.   A method as claimed in any one of claims 1 to 10,
wherein said spatial characteristic includes a measure of
the size of the object.

12.   A method as claimed in any one of claims 6 to 11,
35   wherein said combined spatial characteristic includes
spatial standard deviations from the centroid calculated
for said plurality of preceding images.

13.   A method as claimed in any one of claims 1 to 12,
wherein objects which are not matched to objects in the
preceding image are treated as potential new objects.

5   14.   A method as claimed in any one of claims 5 to 12,
wherein the number of the plurality of preceding images is
about ten.

15.   A method as claimed in any one of claims 1 to 14,
10   wherein the number of images used to generate the
background image is about fifty.

16.   A method as claimed in any one of claims 1 to 15,
wherein objects which have been matched to objects in the
15   preceding frame for a predetermined number of frames are
converted to a line segment, by fitting a straight line
between the centroids of each object.

17.   A method as claimed in claim 16, wherein said
20   line segments are joined to form trajectories showing the
movement of said object across said scene, by determining
whether a following line segment is sufficiently related to
a preceding line element.

25   18.   A method as claimed in any one of claims 1 to 17,
further including masking undesirable image elements by
determining whether the comparison value of an image
element is not sufficiently similar to the background value
too frequently to relate to a moving object and excluding
30   said unreliable image elements from further processing.

19.   A method of reducing the effect of variations in
intensity of illumination of a scene, the method including:
          converting intensity values of image elements of
35   images acquired of said scene to a logarithmic scale of
intensity to thereby form a log-intensity image; and
          filtering said log-intensity image with a high-

pass spatial filter in order to create an output image of
said scene which is independent of the illumination of the
scene.

5   20.   A method as claimed in claim 19, further
including integrating the signal from adjacent pixels in
order to increase the signal to noise ratio of the low
frequency components of the image.

10   21.   A method as claimed in claim 20, further
including decimating the output image in order to create a
further output image having fewer pixels.

     22.   A method as claimed in any one of claims 1 to 18,
15   wherein each image is subjected to the method of any one of
claims 19 to 21 when it is acquired.

     23.   A method of tracking an object added to or
removed from a scene, the method including:
20   (a)   generating a series of background images of the
scene by acquiring for each background image a plurality of
images of said scene, dividing each said image into a
plurality of background image elements, determining a value
of a characteristic of each background image element for
25   each image to obtain a set of values and determining from
said set of values a background value for each of said
background image elements;
            (i)   comparing each new background value
with an old background value of a corresponding background
30   image element of an old background image which precedes
said new background image by a number of background images
to determine whether said new value is sufficiently similar
to said old value to thereby determine whether or not each
new image element is sufficiently similar to the
35   corresponding old image element;
            (ii)   determining from which new image
elements are not sufficiently similar to the corresponding

old image element which new image elements relate to
potential objects and determining a spatial characteristic
of each said potential object;

(b)   matching potential objects in consecutive
5   background images by comparing spatial characteristics of
potential objects of a following background image of said
consecutive images with spatial characteristics of
potential objects of a preceding background image of said
consecutive background images to match potential objects in
10   the following image to potential objects in the preceding
image; and

(c)   treating each matched potential object as an
object added to or removed from the scene.

15   **24.**   A method of tracking an object as claimed in
claim 23, wherein determining a value of a characteristic
for each image element involves determining the mode of a
set of values obtained for each image element from said
plurality of images.

20

  25.   A method of tracking an object as claimed in
claim 24, wherein confidence limits are assigned to each
value and the value of a new background image element is
sufficiently similar to the value of a corresponding old
25   background image element if the mode of a new image element
falls within the confidence limits of the old image
element.

  26.   A method as claimed in any one of claims 22 to
30   25, wherein old background images precede new background
images by three background images and matched potential
objects are treated as new objects if they persist for
three consecutive background images.

35   **27.**   Apparatus for tracking an object moving relative
to a scene, the apparatus including:
(a)   image acquisition means;

(b)   background image generation means for generating
a background image from a plurality of images of the scene
acquired by said image acquisition means, said background
image generation means dividing each image into a plurality
5   of background image elements, determining a value of a
characteristic of each said background image element for
each image to obtain a set of values, and determining from
said set of values a background value for each of said
background image elements;

10   (c)   image comparison means for comparing a pair of
comparison images with said background image by:
             (i)   dividing each image of a pair of
comparison images acquired by said image acquisition means
into a plurality of comparison image elements corresponding
15   to respective ones of the background image elements, and
determining a comparison value of said characteristic for
each of said comparison image elements;
             (ii)   comparing each said comparison value
with said background value of said corresponding background
20   image element to determine whether said comparison value is
sufficiently similar to said background value to thereby
determine whether or not each said comparison image element
is sufficiently similar to the corresponding background
image element; and

25   (iii)   determining from which comparison image
elements are not sufficiently similar to the corresponding
background image element which comparison image elements
relate to potential objects and determining a spatial
characteristic of each said potential object;

30   (d)   object matching means for matching potential
objects in said pair of comparison images by comparing
spatial characteristics of potential objects of a following
image of said pair of comparison images with spatial
characteristics of potential objects of a preceding image
35   of said pair of comparison images to match potential
objects in the following image to potential objects in the
preceding image; and

(e)   object tracking means which treats each matched
potential object as a moving object to thereby track the
movement of each said moving object relative to said scene.

5   28.   Apparatus for tracking an object as claimed in
claim 27, wherein said background image generation means
determination of said background value involves determining
the mode of said set of values.

10   29.   Apparatus for tracking an object as claimed in
claim 27 or claim 28, wherein said background image
generation mean determination of said background value of
said characteristic involves determining a range of
background values, and said image comparison means
15   determines that said comparison value is sufficiently
similar to said background value if said comparison value
is within said range.

30.   Apparatus for tracking an object as claimed in
20   claim 29, wherein said background image generation means
determines said range of background values by calculating
upper and lower confidence limits about the mode of said
set of values.

25   31.   Apparatus for tracking an object as claimed in
any one of claims 27 to 30, wherein said pair of comparison
images are consecutive images in a series of comparison
images acquired by said image comparison means and each
comparison image is compared by said image comparison means
30   with said background image to determine which comparison
image elements relate to potential objects and wherein said
object matching means matches potential objects in a
following image to potential objects in a plurality of
preceding images and said object tracking means treats each
35   object matched to a plurality of preceding potential
objects as a moving object.

32.   Apparatus for tracking an object as claimed in
claim 31, wherein said object matching means combines
spatial characteristics of potential objects of a plurality
of preceding images to produce a combined spatial
5   characteristic for each potential object and matches the
spatial characteristic of the following object to the
combined spatial characteristic.

33.   Apparatus as claimed in any one of claims 27 to
10 32, wherein said image comparison means includes noise
reduction means for processing each comparison image
element which is not sufficiently similar to the
corresponding background image element to reduce the effect
that noise has on image elements being treated as objects.
15

34.   Apparatus as claimed in claim 33, wherein said
image elements are pixels and said noise reduction means
groups pixels into tiles made up of an array of pixels so
that said image is divided into a plurality of tiles, and
20 wherein said noise reduction means determines whether or
not the majority of comparison image elements in said tile
are sufficiently similar and said image comparison means
treats each tile which has a majority of image elements
which are not sufficiently similar as a potential object.
25

35.   Apparatus as claimed in claim 34, wherein said
noise reduction means determines whether each said tile is
sufficiently related to others of said tiles to be an
object, grouping said sufficiently related tiles, and said
30 image comparison means treats said sufficiently related
group of tiles as a potential object.

36.   Apparatus as claimed in any one of claims 27 to
35, wherein said spatial characteristic includes the
35 centroid of the object.

37.   Apparatus as claimed in any one of claims 27 to

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36, wherein said spatial characteristic includes a measure
of the size of the object.

38.   Apparatus as claimed in any one of claims 32 to
37, wherein said combined spatial characteristic includes
spatial standard deviations from the centroid calculated
for the plurality of preceding images.

39.   Apparatus as claimed in any one of claims 27 to
38, wherein said object matching means treats objects which
are not matched to objects in the preceding image as
potential new objects.

40.   Apparatus as claimed in any one of claims 31 to
39, wherein the number of the plurality of preceding images
is about ten.

41.   Apparatus as claimed in any one of claims 27 to
40, wherein the number of images used to generate the
background image is about fifty.

42.   Apparatus as claimed in any one of claims 27 to
41, wherein said object tracking means converts objects
which have been matched to objects in the preceding frame
for a predetermined number of frames to a line segment, by
fitting a straight line between the centroids of each
object.

43.   Apparatus as claimed in claim 42, wherein object
tracking means joins said line segments to form
trajectories showing the movement of said object across
said scene, by determining whether a following line segment
is sufficiently related to a preceding line element.

44.   Apparatus as claimed in any one of claims 27 to
43, further including masking means for masking undesirable
image elements by determining whether the comparison value

of an image element is not sufficiently similar to the
background value too frequently to relate to a moving
object and excluding said unreliable image elements from
further processing.

45.   Apparatus for reducing the effect of variations
in intensity of illumination of a scene, the apparatus
including:

logarithmic conversion means for converting
intensity values of image elements of images acquired of
said scene to a logarithmic scale of intensity to thereby
form a log-intensity image; and

a high-pass spatial filter for filtering said
log-intensity image in order to create an output image of
said scene which is independent of the illumination of the
scene.

46.   Apparatus as claimed in claim 45, further
including integrating means for integrating the signal from
adjacent pixels in order to increase the signal to noise
ratio of the low frequency components of the image.

47.   Apparatus as claimed in claim 46, further
including decimation means for decimating the output image
in order to create a further output image having fewer
pixels.

48.   Apparatus as claimed in any one of claims 27 to
44, wherein each image is processed using the apparatus of
claims 45 to 47 when it is acquired by the image
acquisition means.

49.   Apparatus for tracking an object added to or
removed from a scene, the apparatus including:
(a)   image acquisition means;
(b)   background image generation means for generating
a series of background images of the scene, said background

image generation means generating each background image
from a plurality of images of said scene acquired by said
image comparison means, said background image generation
means dividing each said image into a plurality of
5   background image elements, determining a value of a
characteristic of each background image element for each
image to obtain a set of values and determining from said
set of values a background value for each of said
background image elements;

10   (i)   background comparison means for
comparing each new background value with an old background
value of a corresponding background image element of an old
background image which precedes said new background image
by a number of background images to determine whether said
15   new value is sufficiently similar to said old value to
thereby determine whether or not each new image element is
sufficiently similar to the corresponding old image
element;

             (ii)   determining from which new image
20   elements are not sufficiently similar to the corresponding
old image element which new image elements relate to
potential objects and determining a spatial characteristic
of each said potential object;

     (c)   object matching means for matching potential
25   objects in consecutive background images by comparing
spatial characteristics of potential objects of a following
background image of said consecutive images with spatial
characteristics of potential objects of a preceding
background image of said consecutive background images to
30   match potential objects in the following image to potential
objects in the preceding image; and

     (d)   object tracking means which treats each matched
potential object as an object added to or removed from the
scene.

35

     50.   Apparatus for tracking an object as claimed in
claim 49, wherein said background image generation means

determination of a value of a characteristic for each image
element involves determining the mode of a set of values
obtained for each image element from said plurality of
images.

5

51.   Apparatus for tracking an object as claimed in
claim 50, wherein said background image generation means
assigns confidence limits to each value and said background
comparison means determines that the value of a new
10   background image element is sufficiently similar to the
value of a corresponding old background image element if
the mode of a new image element falls within the confidence
limits of the old image element.

15   52.   Apparatus as claimed in any one of claims 49 to
51, wherein old background images precede new background
images by three background images and said object tracking
means treats matched potential objects as new objects if
they persist for three consecutive background images.

20
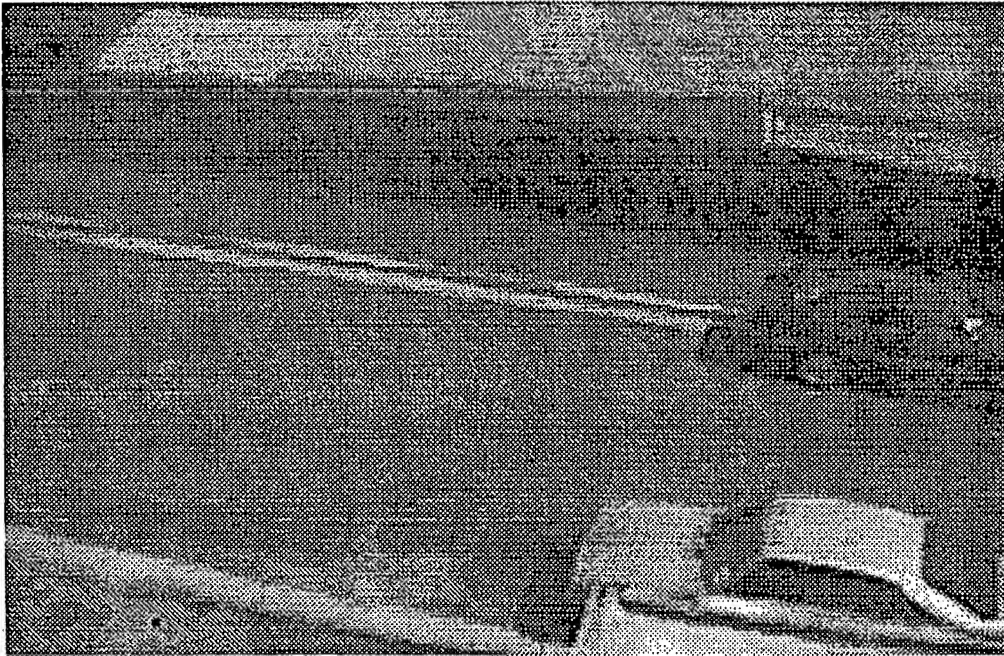
Figure 1
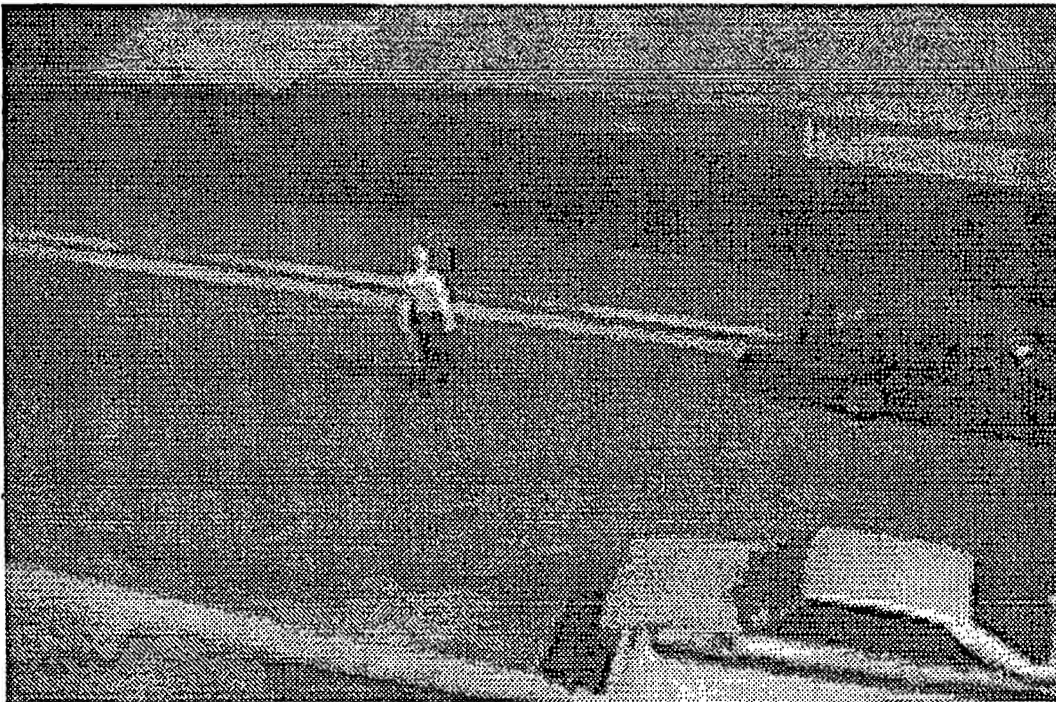
Figure 2
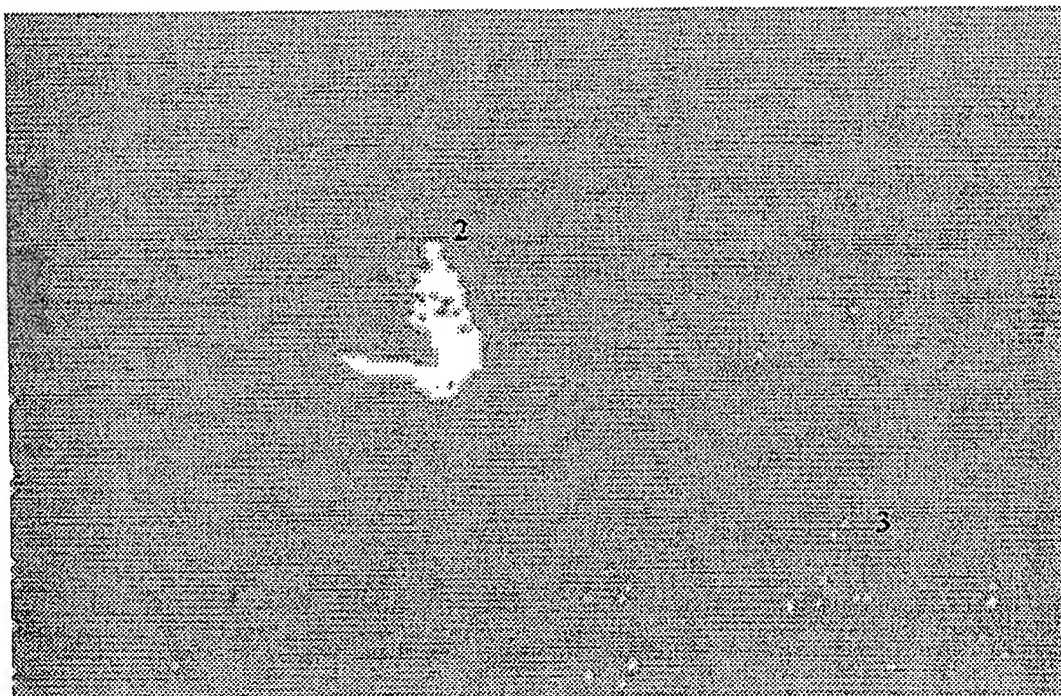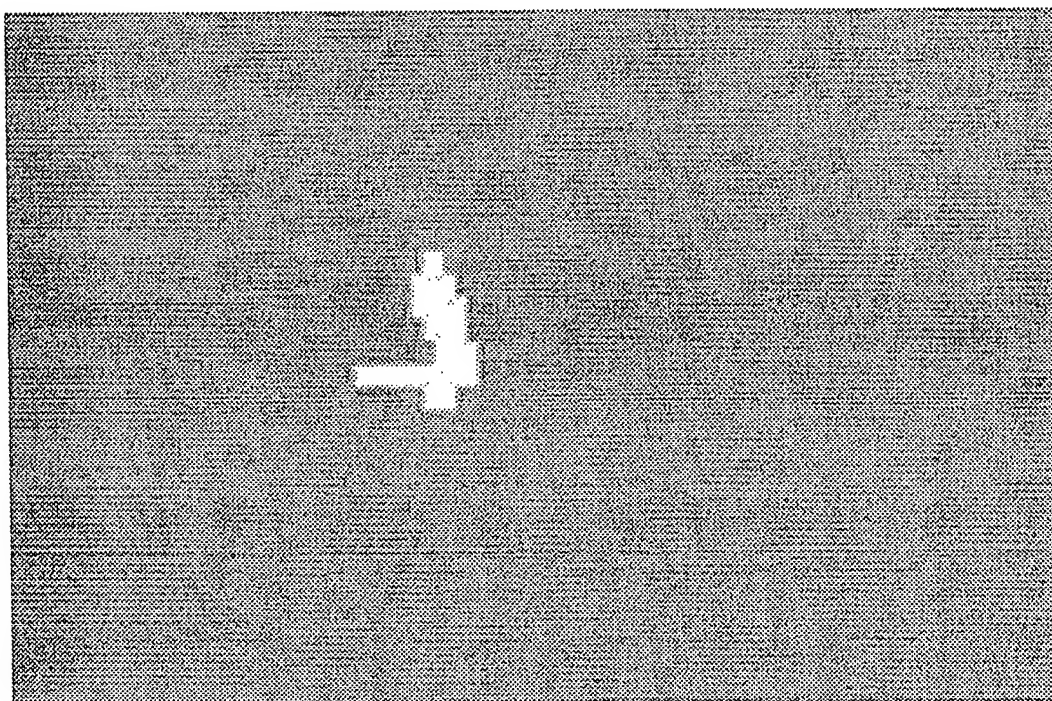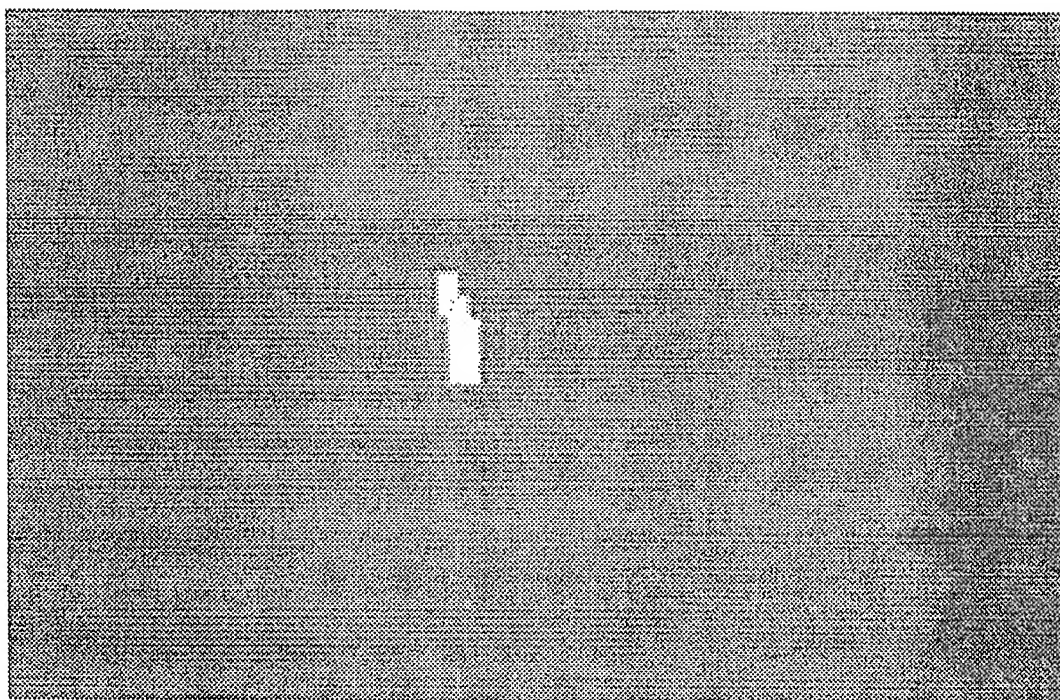
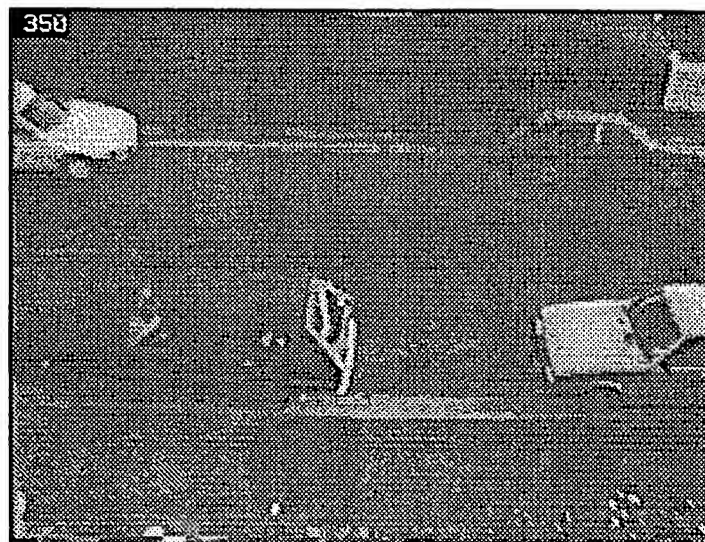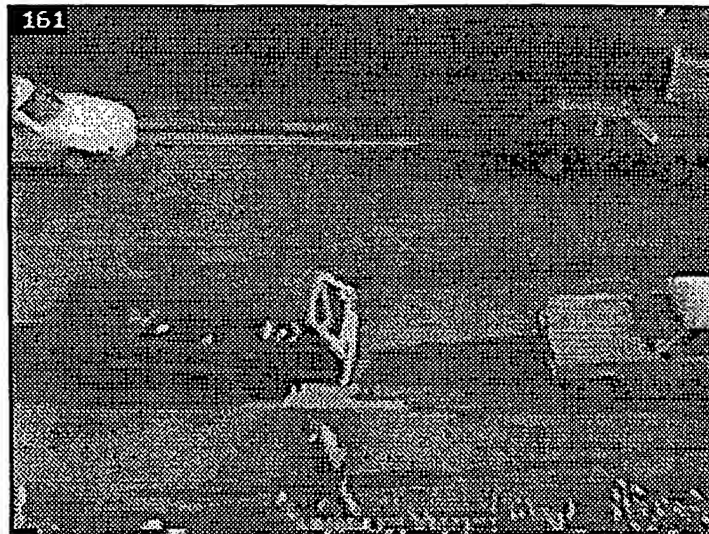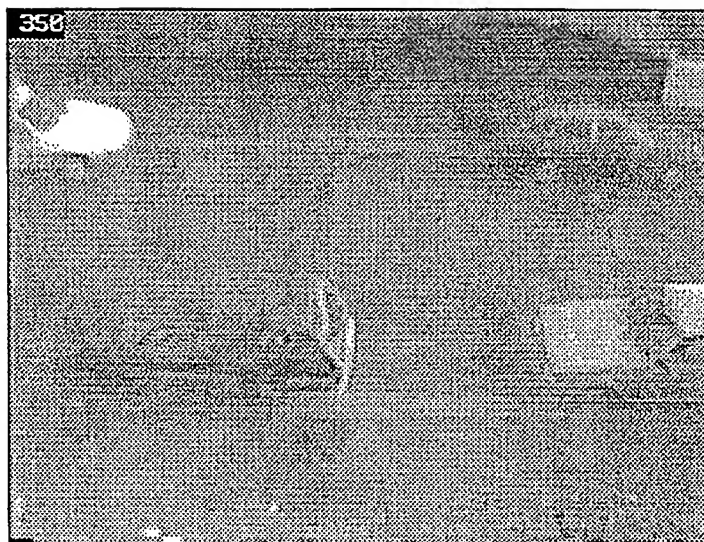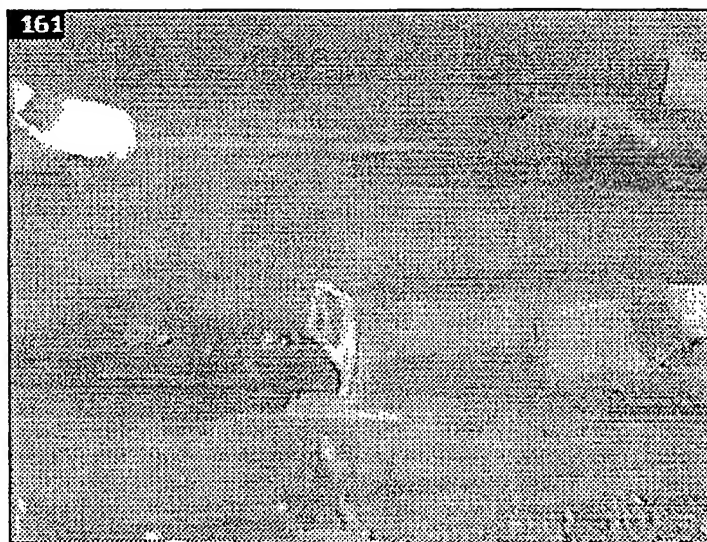Figure 3

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11